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On the Catchability Coefficient of Abalone Fisheries

(Awabi Saiho Gyogyo no Gyokaku Noritsu ni tsuite)

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In this paper we tried to estimate how seriously fishermen's experience and skill explain the catchability coefficient of abalone (*Haliotis discus hannai*) fishery by diving. First we found the principal components of the weather and price data, and then adopted them as explanation variables of the fluctuation of a model of the catchability coefficient. Our results suggest that the fishermen's experience and skill would explain from 1/3 to 2/3 of the fluctuation.

Foreword

The harvest of Ezoawabi (*Haliotis discus hannai*) is carried out in July (momopoly-based operations) and August (enrollment-based operations) in the southern districts of the Akita Prefecture (Kisakata, Konoura) by the naked

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diving method (Fig. 1). One can imagine that the catching efficiency of such operations in which the harvest is carried out without anything looking like real fishing gear, and in such a narrow area, depends to some degree on the experience and skill of the divers. Moreover, oysters, sea cucumbers, edible seaweeds and such are simultaneously harvested in the same area by the same naked diving method. The fluctuations in the values of these harvested organisms together with the fluctuations in the values of abalones affect probably to some extent the fishing efficiency of the abalone harvest. It also stands to reason that the meteorological conditions (weather, direction of the wind)

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affect the efficiency of the same abalone harvest (fishing) efficiency [Kojima et al (1)]. The fishing efficiency of each harvesting day is affected by all these factors. When one thinks that every day may be different, one realizes that this is just following the course of nature.

In the present study, we used the catch data of the abalone harvest in July for the Kisakata region [Akita Prefectural Center for the Promotion of Fisheries (2)], the results of an enquête survey conducted among the operators, the data on the abalone and oyster prices as well as the meteorological data to discuss the importance with regard to fishing efficiency, of the factors causing fluctuations in abalone catch efficiency, and more particularly of the experience and skill of the divers. One may imagine that the solution of these problems will provide information useful for the management of the abalone fisheries. The problems are however difficult and the references limited. We believe that the present study is a first step. The period of data survey covers the three years 1985, 1986 and 1987.

Materials and method

Data

In order to study the catching efficiency of abalone harvesting, we conducted in July 1987 an interview enquête among the operators of the Kisakata region. The results are summarized as hereunder.

(1) It is difficult to harvest abalones when the wind blows from the west or when the transparency of the water is poor.

(2) The direction of the wind has no bearing upon the catch of oysters. These can be caught even when abalone harvesting conditions are bad.

(3) The value of abalones is determined every week through bidding whereas the price of oysters varies from day to day.

(4) When the water temperature rises, the abalones come from under the rocks and are easy to catch.

On the basis of this information, we sought as follows the meteorological and price data.

Aside from abalones, the main organisms to be caught are oysters. As there were no daily price data for the other harvested organisms, we used the price data of oysters and abalone (Table 1).

There are no complete meteorological data for the Kisakata region. Our only choice was to use the data for Sakata City in the Yamagata Prefecture (about 30 km from Kisakata to the south) found in the monthly reports of the Meteorological Agency [3]. Among the data entered in these monthly reports, are data about atmospheric temperature, wind velocity, wind directions, cloudiness, sunshine duration, global solar radiation, amounts of precipitation, all of which are believed to be important to the harvest of abalones. These data are shown in Table 2.

Model of catch efficiency fluctuations

If we denote by X_1, ... X_p the group of variables causing fluctuations in the catch efficiency q, then generally one thinks of the model :

$$q=f(X_1, \cdots X_p)+e \qquad (1)$$

In this model, e is a residual. Of course, the ultimate goal is to determine the function type of this f but there are several important problems. The first problem is that there are no readings for the catching efficiency itself. The next problem is that among the X_1, ...X_p variables, there are also variables which one does not know how to grasp as data like for example the experience - skill (one might simply say "the cleverness") of the diver. Quantifying these experience - skill is an important problem. We want here first to know how great the effect of this experience - skill and the like upon the fluctuations in catch efficiency is.

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In a former report [Hirayama (4)], we proposed the following model of catching efficiency q_t on the harvest day t, based on a questionnaire survey regarding the abalone catch volume per day of harvest, the catching time, the total operation time and such conducted among the fishermen of the Kisakata region.

$$q_t = q_0 \cdot \left(\sum_i \frac{h_{it}'}{h_{it}} \cdot p_{it} \right)^{v} \left(= q_0 A_t^{v} \right) \qquad (2)$$

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Here, q_0 denotes the catch efficiency when operating under optimal harvesting conditions, h_{it} is the total operating time of the diver i on the day t, h_{it}' is the abalone catching time on day t by the same diver, and p_{it} is the abalone catch volume of diver i on day t vs. the total catch volume on day t. v is equal to $(dq_t/q_t)/(dA_t/A_t)$, and expresses the flexible values A_t and q_t.

Applying this catch efficiency model to the DeLury method [Tanaka (5)], one obtains the selection of v and the evaluated value of q_0. Moreover, as the data for the year 1987 were obtained after the publication of our former report [Hirayama et al (4)], we show in Table 3 the questionnaire survey results, and in Table 4 the values of v, q_0. based on these results together with the values already obtained in our former report for 1985, 1986. We show in Fig 2 the residual analysis graph of the regression analysis based on the DeLury method. From these residual graphs, we did not find that this model was particularly impractical. In point of fact, there is every year a limit to the number of abalones caught by one diver per day, so we added a possible model obtained by slightly correcting the model of the above equation, selected v from a wide range, and estimated q_0. As a result of the calculations for 1987, 0.8 was selected for the index v, and 1.872×10^{-4} was selected for q_0.

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This catch efficiency model (2) is the result of the aggregation of a group of variables such as the meteorological conditions, the price conditions, the diver's experience - skill which should affect the catch efficiency. It is expected to be adequate as model for catch efficiency. So, the basic idea of the authors in the present study is that if, using this catch efficiency model, one reverses this model which is calculable through the data to the weather, price variables for which data already exist, then

the parts remaining unexplained in the regressions should be the variables explaining the fluctuations in catch efficiency, that is, the experience - skill of the diver.

Analysis of the principal components which are the weather and the price data

At the present time when it is still impossible to quantify successfully the experience - skill of the divers, it is understood that the group of variables explaining the catch efficiency fluctuations included in f of equation (1) are the weather and the prices. We also assume that f is the linear equation of these variables. In short, using the catch efficiency model (2), we express the equation (1) as :

$$q_t = \beta_0 + \beta_1 x_{t1} + \cdots + \beta_p x_{tp} + \varepsilon_t \qquad (3)$$

The symbol $x_{t1}, \ldots x_{tp}$ denote the weather and the price on the day t. For example, as the atmospheric temperature may be average or maximal, one notes a similar multicollinearity in the group of the p variables. For the regression analysis of the explanatory variables group having multicollinearity, one may conceive two methods, that is, the main components regression method and the Ridge regression method [Chatterjee *et al* (6)]. As the analysis of the principal components which the weather and price data are, is in itself an object of interest, we adopted the principal components regression method. We denote the weather and price data appearing in Table 2 and Table 1 by the following symbols

x_1: average air temperature; x_2 : maximal air temperature; x_3 : average wind velocity; x_4 : maximal wind velocity; x_5 : wind direction; x_6 : cloudiness; x_7 : sunshine duration; x_8 : global solar radiation; x_9 : amount of precipitation; x_{10} : price of oysters; x_{11} : price of abalones.

When we consider this group of variables, we see that the wind direction is a nominal measure, and the cloudiness an ordinal measure, whereas the other variables are measurable. There does not seem to be an established principal components analysis method for the time when differences are admixed in the characteristics of such variables. Basing ourselves on the information obtained through our questionnaire, we converted the wind direction as follows

to ordinal measures, and together with cloudiness, treated the two ordinal measures exactly like measurable data.

1. In the wind direction letters, there is not a single letter W;
2. In the three wind direction letters, there is one W;
3. In the two wind direction letters, there is one W;
4. In the three wind direction letters, there are two letters W;
5. The wind direction is westerly (W).

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In short, these numbers indicate the negativity of the wind direction with respect to abalone harvesting.

Regarding the price data, as we do not know the price of the day, we thought that the price on the previous day should be reflected in the "eagerness" of the organisms collection of the day. For the price on the first harvesting day in July, we used for convenience the average price of the month.

Standardizing all meteorological and price data, we show in Table 5 the eigenvalues of the dispersion - codispersion queues, and the contribution percentages as well as cumulative contribution percentages vs. the various principal components. We show in Table 6 the length-1 eigenvectors that is, the first, second and third principal components vectors vs. the three eigenvalues, starting from the highest. We show in Table 7 the correlation coefficient - the factor loading - of the variables (weather, price) together with the various principal components . We also calculated the various component scores of the total harvesting days on the basis of the eigenvectors. These are shown in Table 8.

We show in Table 9 the interpretations (meanings) of the 1st, 2nd and 3rd principal components of the various years, conceived from these tables, together with the variables in which the absolute values of the factor loadings are at leat 0.7. In the interpretation brackets are shown the interpretations of the principal components when considering jointly the fishing efficiency of the abalone harvesting operations.

The purpose of the principal components analysis in the present study is to prevent multicollinearity in the regression model toward the weather, price data in the model (2). The k number of principal components considered from the viewpoint of summarizing the price variables group, seems to be determined there where the cumulative contribution percentage is 60 - 80 % [Okuno et

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al(7)]. In the present study, in the fluctuation factors of catch efficiency, we endeavor to consider the extent of the experience - skill of the divers. Therefore, since there is a 20 % data loss, it is not realistic to expect that the part unexplained by the regression equation of equation (4) (residual from the regression) would represent the sole experience - skill of the diver, when converting model (3) to the model (4) :

$$q_i = \hat{\beta}_0 + \hat{\beta}_1 z_{i1} + \cdots + \hat{\beta}_k z_{ik} + e_i \qquad (4)$$

in which k principal components are used as explaining variables. However, when one increases the k number of considered principal components, the residual freedon degree ($n - k - 1$) of the regression equation (4) is too small.

With regard to selecting the number of principal components in the present study, there is such a trade-off problem. So, we used therefore the

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following convenient method. According to Okuno et al, when the residuals degree of freedom ($n - k - 1$) is 10 or higher, having 20 should be desirable if possible. As the numbers of data for 1985, 1986 and 1987 are respectively 16, 20, 13, one might also wish not to have a freedon degree of 20. Here, we tried choosing a number of principal components so as to have 10. By doing so, $k = 5$ for 1985, $k = 9$ for 1986, and $k = 2$ for 1987. Table 5 shows that the cumulative contribution percentages of the principal components at this time are respectively 93.6 %, 99.7 % and 61.8 %. The cumulative contribution percentages for 1985 and 1986 are high, but the percentage is low for 1987. So, in order to have a rough arrangement of the cumulative contribution percentages, we adopted $k = 5$ ($n - k - 1 = 7$, cumulative contribution percentage of 93 %) for 1987, and $k = 5$ ($n - k - 1 = 14$, cumulative contribution percentage of 93.4 %) for 1986.

Regression analysis

Using the chosen v and q_o ($v = 0.8$, $q_o = 3.314 \times 10^{-4}$ for the year 1985; $v = 0$ was chosen in Table 4 for the year 1986 and $q_t = q_o$, so for the sake of convenience we adopted here $v = 0.1$, $q_o = 3.381 \times 10^{-4}$; for the year 1987, $v = 0.8$, $q_o = 1.872 \times 10^{-4}$), we performed the regression analysis, using q_t calculated from the catch efficiency model (2) as the target variable, and the principal component scores on the various harvesting days (Table 8) as the explaining variables.

Results

The regression equations obtained from the regression analyses, are for the years 1985, 1986, 1987 respectively :

$$q_1 = 0.132z_{11} + 0.294z_{12} - 0.064z_{13} - 0.065z_{14} - 0.416z_{15}$$
$$q_2 = -0.297z_{21} - 0.361z_{22} - 0.348z_{23} - 0.162z_{24} - 0.344z_{25}$$
$$q_3 = -0.027z_{31} - 0.208z_{32} + 0.735z_{33} + 0.186z_{34} - 0.260z_{35}$$

The coefficient β_i *is the standard regression coefficient. As the equation suggests, the first principal component chosen in the analysis of the weather, price data which are the principal components is not necessarily the most "effective" variable in this regression equation. This seems to be natural since the analysis of the principal components is pursued irrespective of catch efficiency. As a result of obtaining the parts remaining unexplained in this regression equation, i.e. , (1 - determining coefficient), we found 0.71, 0.52, 0.31 for the years 1985, 1986 and 1987. Because of this, we discovered that the proportion of experience - skill of the divers in the fishing efficiency varies greatly from 1/3 to 2/3 according to the years. The fact that (1 - determining coefficient) expresses the experience - skill of the divers, seems to be particularly true when the weather - price data are orthogonal vs. the experience - skill data. Yet, as long as the latter data are not available, they do not have to be verified. When the relationship is not orthogonal, (1 - determining coefficient) expresses within the experience - skill, the portion unrelated to the weather - prices. This does not mean that indicating the experience - skill is meaningless. When quantifying the experience - skill, one may also imagine variables whereby the diving capability for example could be affected by the weather. If however, only the years of experience are considered, these remain unrelated to the weather and prices. In the present abalone harvesting operations in which the collection days are also determined by weather considerations, one is rather assuminmg that the experience - skill of the diver are unrelated to the weather - price data.

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*translator's note : uncertain; not quite clear in text

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Discussion

Regarding the method proposed by the author of estimating the proportion held by the experience - skill of the diver in the fishing efficiency, there remain the following problems. The first problem is to know the extent to which the fishing efficiency model shown in equation (2) is adequate. There occurs here also the problem of absence of adequate model verification as in the numerical studies regarding the analysis of numerous resources. This seems to be an interesting problem from a statistical viewpoint. Many-sided studies

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however remain to be conducted. There is the study about the principal component analyses conducted at the time when there is an admixing of variables with diverse measuring levels (for the quantification of the wind direction, we applied other regular intervals such as 11, 12, 13, 14, 15 or 2, 4, 6, 8, 10 to tentatively extract the principal components, but the results did not change at all). There is the study regarding the selection of the principal components numbers when switching from the analysis of the principal components to the regression analysis. There is also the study regarding the evaluation of the created models when from the start one does not know quite well the fluctuations of the left-side variables through the sole variables on the right side as in equation (4), and when one does know those same fluctuations.

At the close of this study, we wish to thank Mr. Masaru MURAOKA, Head of the Culture Department at the Akita Prefectural Center for the Promotion of Fisheries, Mr. Jun'ichi YAMADA of the same center, Mr. Mago ** SATO, Head of the Southern Akita Fisheries Cooperative as well as the personnel of the same body, and finally Mr. Hiroshi KIKUCHI of the Tokai Fisheries Research Center who helped us in the present study.

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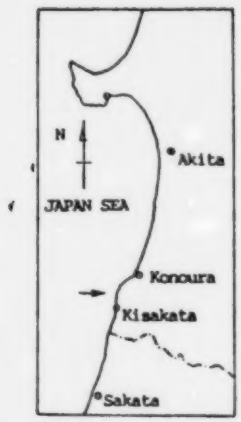

Fig. 1. Location of abalone fishing ground.

Table 1. Prices of oyster and abalone at fish market in Kisakata.

Date	July 1985		July 1986		July 1987	
	Oyster	Abalone	Oyster	Abalone	Oyster	Abalone
3	88.6	4520.6	51.6	4761.7	39.6	5777.2
4	91.8	4525.8	77.5	4744.3		
5	53.3	4580.3			48.5	5676.4
6			29.9	4923.0	51.3	5709.9
7			24.3	4817.0		
8	53.2	4552.1			41.7	6300.8
9			26.1	4822.9	38.2	5762.7
10	22.0	4616.0	21.9	4819.4		
11	29.8	4503.9	21.7	4844.7		
12						
13						
14					63.6	6307.2
15			43.0	4886.7	74.9	6312.5
16			51.2	4736.7	61.1	6278.8
17	43.0	4595.3	53.7	4792.9		
18						
19					53.8	6266.0
20			55.8	4763.2	55.0	6224.2
21	31.0	4623.3	52.7	4805.7	44.2	6583.2
22	30.1	4594.9	54.4	4809.4		
23	26.8	4595.7				
24	23.4	4590.2	53.2	5000.0		
25	23.9	4663.5	44.7	4915.3		
26	22.5	4656.7			58.9	6440.4
27			49.5	4818.0		
28	32.2	4622.1	29.2	4750.7		
29	27.4	4643.4	16.8	4953.3		
30	21.1	4592.4	39.9	4808.5		
31			41.7	4724.8	139.7	6588.3

Notes: The price units of Oyster and Abalone are Yen/individual, Yen/kg respectively.

Table 2. Observed values of weather elements in Sakata.

No.	Date	Air temperature		Wind speed		Wind Direction	Mean of Cloud Amount 0.1	Sunshine Duration 0.1 h	Global Solar Radiation 0.1 MJ/m²	Total Amount of Precipitation 0.1 mm
		Mean 0.1°C	Max. 0.1°C	Mean 0.1 m/s	Max. 0.1 m/s					
1985										
1	3	217	264	18	43	NNW	98	101	208	0
2	4	198	216	24	57	ESE	100	0	45	210
3	5	213	258	20	43	ESE	100	20	130	10
4	8	215	247	22	45	WNW	100	32	126	25
5	10	241	296	25	52	SE	88	100	199	0
6	11	228	272	46	77	SW	100	14	76	245
7	17	208	250	31	2	ESE	100	4	81	15
8	21	255	302	23	0	WNW	28	119	252	0
9	22	231	278	27	1	W	83	14	74	70
10	23	242	287	29	59	SW	90	90	220	25
11	24	248	290	22	41	WNW	33	113	240	0
12	25	262	314	22	42	NW	30	126	250	0
13	26	276	318	23	54	N	0	124	240	0
14	28	267	297	22	41	NW	0	127	244	0
15	29	262	296	25	53	W	55	92	206	0
16	30	255	292	26	45	NNW	80	111	223	0
1986										
1	3	183	227	22	47	NW	100	4	113	5
2	4	181	218	24	51	WSW	75	76	200	15
3	6	197	217	21	54	WSW	100	0	48	110
4	7	192	217	17	41	WNW	100	0	84	110
5	9	200	243	21	50	NNW	68	79	218	10
6	10	197	224	31	61	NNW	85	48	141	0
7	11	210	245	22	49	N	70	47	183	0
8	15	200	223	24	53	SE	100	0	40	200
9	16	205	228	29	66	WSW	100	0	40	100
10	17	220	236	34	72	ESE	100	1	76	40
11	20	216	277	30	57	E	78	105	252	0
12	21	212	264	51	67	ESE	50	91	247	0
13	22	200	233	65	90	ESE	98	1	96	245
14	24	195	219	28	46	WNW	95	20	164	0
15	25	199	237	22	51	WNW	55	91	245	0
16	27	242	299	23	37	W	60	87	231	0
17	28	255	299	27	59	W	3	128	268	0
18	29	257	314	25	37	WNW	0	130	263	0
19	30	264	332	28	43	SE	5	130	259	0
20	31	272	331	27	54	NNW	5	130	247	0
1987										
1	3	211	286	39	88	N	83	48	122	100
2	5	215	273	27	60	NW	55	91	223	0
3	6	208	248	39	79	E	95	10	84	55
4	8	212	256	26	55	NW	13	126	269	0
5	9	244	314	34	58	ESE	75	109	222	0
6	14	241	282	24	54	NNW	68	47	160	5
7	15	232	261	20	55	NNW	100	23	126	205
8	16	277	323	49	88	ESE	90	103	228	0
9	19	251	297	21	48	N	93	53	183	0
10	20	253	299	39	72	ESE	25	125	248	0
11	21	245	274	24	47	NW	65	85	222	0
12	26	243	268	26	49	WNW	100	27	159	5
13	31	234	267	22	60	SE	85	0	33	450

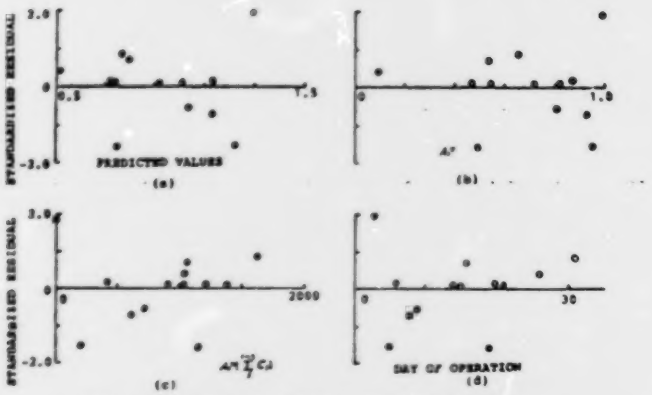

Fig. 2. Standardized residuals versus predicted values.

Table 3. Catch table of abalone at Kisakata in July of 1987.

No.	Date	Total		Questionnaire			
		Effort	Catch	Effort		Catch	
		Number of fishermen	Weight (kg)	Number of fishermen	Operation hour (h)*1 X_t	Weight (kg)	Number C_t*2
1	3	65	232.7	16	37.9	72.2	400
2	5	63	227.1	16	54.2	75.1	399
3	6	61	199.1	16	45.2	66.3	380
4	8	55	154.2	15	39.7	55.1	356
5	9	61	200	16	53.4	61.3	379
6	14	59	207.4	15	51.5	52.6	317
7	15	62	184.4	16	51.2	57	339
8	16	62	159.7	14	41.2	42.4	259
9	19	52	95.3	13	40.6	33.4	224
10	20	60	139.5	14	43.9	41.4	259
11	21	56	126.6	15	44.8	37.5	252
12	26	40	54.4	9	21.9	9.5	70
13	31	29	23.1	9	8.4	3.4	22

*1 $X_t=\sum_i h_{it}'$, where h_{it}' shows operating hour spent for catching abalone by fisherman i on t-th day.

*2 $C_t=\sum_i C_{it}$, where C_{it} shows catch in number of abalone caught i by fisherman i on t-th day.

Table 4. Values of the multiple correlation coefficient R and estimated values of catchability coefficient q_0 related to the expoent.

Year	1985		1986		1987			
Criterion	25		20		20		25	
ν	R	$q\times10^{-4}$ (h^{-1})	R	$q\times10^{-4}$ (h^{-1})	R	$q\times10^{-4}$ (h^{-1})	R	$q\times10^{-4}$ (h^{-1})
0.0	0.733	3.082	0.744*	3.411*	0.877	3.351	0.877	3.351
0.1	0.742	3.115	0.742	3.381	0.883	3.195	0.886	3.177
0.2	0.750	3.148	0.739	3.351	0.888	3.040	0.894	3.000
0.3	0.757	3.179	0.738	3.321	0.891	2.886	0.900	2.820
0.4	0.762	3.208	0.730	3.292	0.893	2.732	0.906	2.636
0.5	0.766	3.237	0.725	3.263	0.894	2.580	0.910	2.450
0.6	0.768	3.264	0.719	3.235	0.894	2.428	0.918	2.260
0.7	0.770	3.290	0.712	3.208	0.892	2.277	0.914	2.068
0.8	0.771*	3.314*	0.705	3.180	0.891	2.126	0.915*	1.872*
0.9	0.770	3.336	0.698	3.154	0.888	1.976	0.915	1.674
1.0	0.768	3.357	0.690	3.128	0.885	1.826	0.914	1.473

* The numericals show the maximum value of multiple correlation coefficient (R) in each case and the estimates related to the maximum value of R.

Table 5. Eigenvalue and cumulative.

Principal component No.	1985			1986			1987		
	Eigenvalue	Percent	Cumulative	Eigenvalue	Percent	Cumulative	Eigenvalue	Percent	Cumulative
1	5.96	54.2	54.2	5.00	45.5	45.5	3.59	32.6	32.6
2	2.61	23.7	77.9	2.30	20.9	66.4	3.22	29.2	61.8
3	0.86	7.9	85.8	1.40	12.7	79.1	1.95	17.7	79.5
4	0.55	5.0	90.8	0.90	.2	87.3	0.85	7.7	87.5
5	0.31	2.8	93.6	0.67	.1	93.4	0.63	5.7	93.0
6	0.28	2.6	96.2	0.29	6	96.0	0.41	3.7	96.7
7	0.25	2.3	98.5	0.21	.9	97.9	0.20	1.8	98.5
8	0.11	1.0	99.4	0.15	1.4	99.3	0.11	1.0	99.5
9	0.03	0.3	99.8	0.05	0.5	99.7	0.05	0.4	99.9
10	0.02	0.2	100.0	0.02	0.2	99.9	0.007	0.1	100.0
11	0.005	0.0	100.0	0.01	0.1	100.0	0.006	0.0	100.0

Table 6. Normalized eigenvectors.

X_i	1985			1986			1987		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
1	0.382	0.154	−0.129	0.365	0.205	−0.088	0.237	0.285	−0.[illegible]
2	0.371	0.148	−0.174	0.400	0.200	−0.081	0.363	0.309	−0.190
3	−0.155	0.508	−0.292	−0.121	0.577	0.008	0.295	0.298	0.370
4	−0.184	0.505	−0.076	−0.236	0.503	0.043	0.127	0.341	0.506
5	0.122	0.274	0.891	0.068	−0.402	0.470	−0.037	−0.411	−0.255
6	−0.346	−0.034	0.083	−0.417	−0.141	−0.004	−0.293	0.307	−0.150
7	0.386	−0.083	−0.144	0.421	0.122	0.083	0.492	−0.123	−0.010
8	0.384	−0.126	−0.089	0.397	0.100	0.141	0.473	−0.200	−0.137
9	−0.282	0.326	−0.157	−0.313	0.144	−0.255	−0.390	0.194	0.007
10	−0.251	−0.370	0.020	−0.130	0.131	0.722	0.026	0.407	−0.066
11	0.292	0.315	0.086	0.091	−0.297	−0.386	−0.051	0.312	−0.498

Notes: X_i: Variable, Z_i (i=1, 2, 3): Principal component.

Table 7. Factor loading.

X_i	1985			1986			1987		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
1	0.933	0.248	−0.120	0.817	0.311	−0.104	0.449	0.510	−0.642
2	0.905	0.239	−0.162	0.895	0.304	−0.096	0.688	0.554	−0.265
3	−0.378	0.821	−0.272	−0.270	0.875	0.009	0.559	0.534	0.517
4	−0.450	0.815	−0.071	−0.528	0.762	0.051	0.241	0.612	0.706
5	0.298	0.442	0.828	0.152	−0.610	0.555	−0.070	−0.736	−0.356
6	−0.845	−0.055	0.077	−0.933	−0.214	−0.005	−0.555	0.550	−0.210
7	0.943	−0.134	−0.134	0.942	0.185	0.098	0.933	−0.221	−0.014
8	0.937	−0.203	−0.082	0.887	0.151	0.167	0.895	−0.359	−0.191
9	−0.689	0.526	−0.146	−0.701	0.218	−0.302	−0.738	0.348	0.010
10	−0.614	−0.598	0.019	−0.292	0.199	0.854	0.050	0.729	−0.092
11	0.713	0.509	0.080	0.204	−0.450	−0.456	−0.097	0.559	−0.695

Notes: X_i: Variable, Z_i (i=1,2, 3): Principal component.

Table 8. Principal component scores.

No.	Date	Z_1	Z_2	Z_3	Z_4	Z_5
1985						
1	3	−0.050	−1.615	0.218	0.557	−0.793
2	4	−4.921	−1.025	−0.382	−1.658	−0.252
3	5	−2.436	−2.733	−0.188	−0.346	0.668
4	8	−1.590	−0.895	1.615	0.150	−0.472
5	10	−0.012	−0.972	−1.186	0.503	0.962
6	11	−2.893	4.388	−0.860	−0.026	−0.175
7	17	−2.872	−0.476	−0.679	1.590	−0.352
8	21	1.993	−0.142	0.469	−0.410	0.754
9	22	−1.297	2.197	1.571	0.168	0.349
10	23	0.280	0.776	−0.122	.758	0.428
11	24	1.931	−0.462	0.723	062	−0.283
12	25	2.568	−0.397	−0.199	133	0.468
13	26	3.100	0.521	−1.579	0.868	−0.104
14	28	3.410	−0.009	−0.052	−0.742	−0.836
15	29	1.600	0.821	1.204	−0.017	0.491
16	30	1.486	0.023	−0.553	0.483	−0.554
1986						
1	3	−1.409	−1.456	0.179	−0.765	0.130
2	4	−0.498	−0.784	1.550	−0.824	0.314
3	6	−2.593	−0.686	2.090	0.344	−1.291
4	7	−1.575	−2.544	−1.054	0.751	−0.152
5	9	0.476	−0.560	−0.701	−1.226	0.350
6	10	−0.844	−0.020	−0.703	−0.960	0.581
7	11	0.208	−0.414	−1.248	−1.445	0.063
8	15	−2.468	−0.445	−2.322	0.060	−1.011
9	16	−2.212	−0.589	−0.258	1.301	−0.164
10	17	−2.056	1.467	0.237	−0.818	−0.687
11	20	0.780	1.096	0.536	−0.928	0.603
12	21	0.307	2.693	0.853	−0.663	1.006
13	22	−3.709	3.792	−0.594	1.557	0.360
14	24	−1.010	−1.120	1.263	−0.333	0.290
15	25	0.868	−1.492	0.404	1.227	2.059
16	27	2.160	−1.396	0.429	1.234	0.009
17	28	2.872	0.582	1.347	1.065	−0.404
18	29	3.549	0.076	0.335	−0.278	−1.460
19	30	3.829	0.438	−2.299	0.492	0.278
20	31	3.323	1.409	−0.049	0.207	−0.871
1987						
1	3	−0.422	1.585	1.948	−0.115	0.366
2	5	0.492	−2.393	0.729	−0.293	−0.026
3	6	−1.773	0.166	2.926	−1.095	0.100
4	8	1.298	−3.141	0.894	1.450	0.666
5	9	1.678	0.330	−0.576	−0.574	−1.420
6	14	−0.249	−1.369	0.062	−0.791	−1.169
7	15	−2.283	0.456	−0.832	0.562	0.579
8	16	2.861	3.578	−0.059	−0.246	0.927
9	19	−0.062	0.717	−1.566	−0.088	−0.631
10	20	2.750	0.498	0.239	0.935	−0.388
11	21	0.420	−1.177	−1.428	0.197	0.615
12	26	−1.196	−0.861	−1.998	−1.481	1.013
13	31	−3.514	1.623	−0.340	1.538	−0.633

Notes: Z_l (l=1, 2, 3, 4, 5): Principal component.

Table 9. Variables whose absolute values of factor loading are above 0.7 and interpretation of principal component 1, 2, 3 in 1985, 1986 and 1987.

		Factor loading		Interpretation (Related to the abalone fishery)
		+	−	
1985	Z_1	X_1, X_2, X_7, X_8 X_{11}	X_6	Warmth and the price of abalone (Good condition for abalone fishery according to listening findings (4))
	Z_2	X_3, X_4	NO	Wind speed
	Z_3	X_5	NO	Wind direction (Bad condition for the abalone fishery)
1986	Z_1	X_1, X_2, X_7, X_8	X_6, X_9	Warmth
	Z_2	X_3, X_4	NO	Wind speed (Related to X_5 in −0.61, so it's good condition for the abalone fishery)
	Z_3	X_{10}	NO	Price of Oyster (Operation preference seen from price)
1987	Z_1	X_7, X_8	X_9	Goodness of weather condition
	Z_2	X_{10}	X_5	Operation preference for Oyster
	Z_3	X_4	X_{11}	Not clear